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Multi-objective game theory model and fuzzy programing approach for sustainable watershed management

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ABSTRACT

This study was carried out with the aim of feasibility evaluation of the application of multi-objective game theory and fuzzy programing approaches for settling balance between economic development and environmental impact as well as to facilitate the respective decision-makings in Zemkan basin, west of Iran. The bi-objectives of multi-objective game theory and fuzzy programing approaches are minimizing the destructive effects on the environment (less erosion and sediments) and maximizing the economical incomes resulted from different land uses (more net present value). Satellite images were used for recognition of different land uses and the areas of these land use. In this study, the environmentalists and Zemkan basin users were selected as environmental and economical players, respectively. The results reveal that Nash bargaining solution, which is the result of the multi-objective game theory model, differs from Pareto optimalities, obtained through the classical multi-objective model. Nash bargaining solution offered more satisfactory solutions based on decision-makers' priorities. In addition, the overall results showed that the results of fuzzy programming approach were very close to the results of the multi-objective game theory model. Therefore, in both methods, the decision variables of semi-closed forest, open forest, non-irrigated agricultural lands and barren rocky lands were eliminated and the ones of rural areas, urban areas, and water body remained unchanged. The innovation of multi-objective game theory and fuzzy programing approaches, which can be understood and interpreted well by decision makers, is setting a kind of balance between economic and environmental concerns in watershed management. The results also show that multi-objective game theory and fuzzy programing approaches can be applied to many other issues concerning the environmental management. The upcoming researches can concentrate on developing a third objective like social concerns and accordingly tri-objective games would be applied instead of bi-objective ones.

1. Introduction

Watershed management is at the intersection of environmental and social sciences because water sustains a broad range of ecosystem services, and society needs a reliable water supply for drinking, food production, waste treatment, industry, and recreation (Tomer, 2014). Watershed models may be classified into four categories according to their scope and purpose (Mirchi et al., 2009): engineering-based watershed process models (Chen et al., 1982; Abaci and Papanicolaou 2007; Wang et al., 2009; Habarth and Barkdoll 2009), hydro economic models (Lund and Ferreira 1996; Draper et al., 2003; Jenkins et al., 2004; Maneta et al., 2009), multi-criteria (multi-objective) decision-making models (Duckstein and Opricovic 1980; Gershon and Duckstein 1983; Wen and Lee 1998; Lamy et al., 2002), and conflict resolution models (Rogers 1969; Lee and Chang 2005; Lee 2012; Üçler et al., 2015). As far as the watershed management is concerned, decision making would be challenging to select an appropriate alternative among the available alternatives (Lund and Palmer, 1997). Naturally, the criteria are contradictory and non-commensurable, and these decisions can be controversial (Lee and Chang, 2005), because it is often difficult to satisfy all stakeholders having different interests, values and views (Shields et al., 1999). In issues of watershed management, there has been revealed the conflict between the economic gains resulting from land-use development (wood cultivation, development of agricultural Land, and recreational activities), and environmental objectives (water and soil conservation and reduction of eutrophication) (Lund and Palmer, 1997). The conflict between the environmental approach of governmental decision makers in Zagros basins and economical approach of local people residing in those basins has led to the fact that the majority of decision-makers, in order to attain the balance

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among contradictory objectives, strive to reach a consensus solution. In the condition that these goals are contradictory, the improvement in one goal only and only will lead to missing the other (Raquel et al., 2007). Game theory multi-objective method and fuzzy programming approach are among the multi-objective programming issues addressing conflicting situations.

Game theory, which originated with the pioneering work of Von Neumann and Morgenstern (1944), is the study of mathematical models of conflict and cooperation between intelligent rational decision-makers (Bočková et al., 2015). It is also a powerful instrument in determining the equilibrium points of decision makers and is applied in the analysis of situations in which two or more people should make a decision in a condition that everyone's decision affects the outcomes of the other's. Game theory has applications in a variety of fields including economics (Camerer, 1997) and social sciences (Myerson, 1992). It has also been used in water resources management (Parrachino et al., 2006a,b; Carraro et al., 2007; Homayounfar et al., 2010; Sobuhi and Mojarad, 2010), determination of the optimal consume rate of underground waters (Mazandarani Zadeh et al., 2010; Pourzand and Zibaei, 2010), wood market (Mohammadi Limaei, 2006, 2007), paper market (Mohammadi Limaei, 2010), forest management (Rodrigues et al., 2009; Shahi and Kant, 2007) and watershed management (Lee, 2012; Üçler et al., 2015).

Fuzzy set theory which was introduced by Zadeh (1965), consequently has been developed in different fields. Zimmermann (1978) introduced fuzzy linear programming with multiple objective functions and then fuzzy set theory was involved in the other aspects of decision-making. He showed that results obtained by fuzzy linear programming always yield efficient and optimal compromise solutions. The fuzzy programming approach is a widely used technique to solve bi-objective decision-making problems. In the literature, Sommer and Pollatschek (1978) first established the application of fuzzy programming to an air pollution regulation problem. Bogardi et al. (1983) presented the aquifer management planning under a fuzzy environment. Slowinski (1986) applied a multi-criteria fuzzy linear programming method for water supply systems planning. Xiang et al. (1992) specifically discussed land use planning by fuzzy multi-criteria decision-making techniques. Julien (1994) proposed a fuzzy linear programming technique for water quality management planning in a typical river basin system. Chang and Wang (1996, 1997) applied fuzzy goal programming in dealing with two integrated solid waste management issues in Taiwan. It is therefore believed that the fuzzy mathematical programming approach should result in more realistic and flexible optimal solutions for the sustainable development and management of land use in a reservoir watershed or river basin. Chang et al. (1997) applied a fuzzy multi-objective programming approach for solving the optimal strategies between the utilization of carrying capacity of the land and consumption of assimilative capacity of the reservoir storage within the reservoir watershed. Chen et al. (2011) described the design of a fuzzy decision support system in multi-criteria analysis approach for selecting the best plan alternatives or strategies in environment watershed. In fuzzy programming approach, the aim is to find a compromise solution that maximizes the satisfaction degree of all membership functions, after constructing the membership functions of the objectives (Üçler et al., 2015).

Soil erosion is the most important factor of degradation in watersheds and it poses a serious problem for the environment. Soil erosion also leads to environmental damage through sedimentation, pollution and increased flooding (Shi et al., 2012). Soil erosion is considered as one of the most important causes of land degradation in Iran. Watershed protection plans have been applied to control the soil erosion in different basins by the Forests, Rangeland and Watershed Management Organization of Iran. However, multi-objective game theory and fuzzy programing approaches have not previously been used in watershed management in Iran but it has been used in the other parts of the world such as China (Lee, 2012) and Turkey (Üçler et al., 2015) with satisfactory results. In this paper, multi-objective game theory and fuzzy programing approaches were used in order to set balance between economic development and environmental impact in Zemkan basin, located in the west of Iran. Local people, because of their great reliance on Zagros watersheds, take the economic approach towards them, which is in conflict with the government's environmental one. In this study, multi-objective game theory and fuzzy programing approaches were used to investigate their interaction and conflict analysis.

2. Material and methods

2.1. Multi-objective model

A classical model of multi-objective programming is as follows:

$$\begin{aligned} &\textit{Max or Min } Z(x)=[Z_1(x), Z_2(x), \dots, Z_p(x)] \\ &s.\ t.\ g_j(x) \le 0,\ j= 1, 2,\dots, m \\ &x_k \ge 0,\ k= 1, 2,\dots, n \end{aligned} \quad (1)$$

Where $Z(x)$ is an objective function and $[Z_1(x), Z_2(x), \dots, Z_p(x)]$ is a set of all p objective functions. $g_j(x)$ is the j th constrain function and x_k is the k th decision variable.

In multi-objective problems, instead of one objective function, several objective functions should be optimized simultaneously. When this happens, there will be resulted in more than one optimal response to the related problems which are called pareto optimal responses. Actually, the goal of multi-objective optimization is to find a set of pareto responses.

Regarding its nature, multiple objectives of watershed management can be social, economic, and environmental, such as minimization of water pollution and erosion, maximization of the water and soil conservation, and maximization of the economic gain resulting from land use. In this paper, the maximization of economic income and the minimization of erosion are considered as economic and environmental objectives respectively. Therefore, the objective functions of the bi-objective programming model are as follows:

$$\textit{Min}\quad P= Z_1(x) \quad (2)$$

$$\textit{Max}\quad D= Z_2(x) \quad (3)$$

After determining the objective functions and formulating the problem via proper constraint, the set of pareto responses was obtained.

2.2. Multi-objective game theory model (MOGM)

In order to employ multi-objective game theory model for bi-objective problems of economical–environmental balance, there were selected two groups of environment stakeholders as two players. The advocates of preserving environment and forests (forests, ranges and watershed organization, environmental organization and other environmental NGOs), play the role of player 1 (ecologist player) and Zagros forests users (local people, stakeholders, forest dwellers, etc.) play the role of economist player (player 2).

To determine the negotiation interval of the game and also as a payoff in the game theory analysis, each player wants to know his/her maximum (P_{max} or D_{max}) or minimum values (P_{min} or D_{min}) from the optimization of each individual single objective analysis. Individual maximum and minimum values were calculated for each player by solving a traditional linear programming problem. Therefore, the range of the maximum and minimum values (P, D) for each player was determined as follows:

$$\text{For player 1 } P_{min} \le P = Z_1(x) \le P_{max} \quad (4)$$

$$\text{For player 2 } D_{min} \le D = Z_2(x) \le D_{max} \quad (5)$$

A pair of simulated values i.e. $Z_1(x)$ and $Z_2(x)$ is the outcome of initial MGOM results. The first round of bargainings begins as soon as